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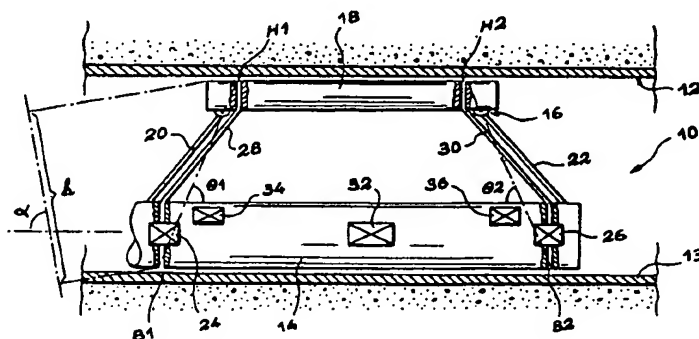
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(54) Title: A METHOD AND APPARATUS FOR DETERMINING THE MEAN DENSITY OF A FLUID FLOWING IN A HYDROCARBON WELL THAT IS INCLINED OR HORIZONTAL



(57) Abstract: To determine the mean density of a fluid flowing along a hydrocarbon well (12), the pressure difference between two regions (H1, B1; H2, B2) situated in the vicinities of the bottom generator line and the top generator line of the well is measured. To this end, a pressure sensor (24, 26) is placed on a tube (28, 30) whose ends open out into the above-mentioned regions, the tube being mounted on an arm (20, 22) that is hinged to the body (14) of the apparatus. The inclination of the straight line joining the two pressure take-off regions (H1, B1; H2, B2) is also determined. The desired mean density is calculated from the measured pressure difference and from the determined inclination.

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A METHOD AND APPARATUS FOR DETERMINING THE MEAN DENSITY  
OF A FLUID FLOWING IN A HYDROCARBON WELL THAT IS INCLINED  
OR HORIZONTAL

DESCRIPTION

5   **Technical field**

The invention relates to a method designed to determine the mean density of a fluid flowing in a hydrocarbon well that is in production, when said well is inclined or horizontal.

10       The invention also relates to apparatus for implementing the method.

**State of the art**

15       A conventional technique for determining the mean density of a fluid flowing in a hydrocarbon well in production consists in measuring the difference in pressure that exists between two points that are substantially in alignment parallel to the axis of the well and that are spaced part from each other along said  
20   axis. For a given distance in a vertical direction between the two pressure take-off points, the measured pressure difference is proportional to the mean density of the fluid.

25       In practice, that technique is implemented by means of apparatus comprising a tool body lying on the axis of the well or parallel thereto. The tool body supports, parallel to its axis, a tube that is open at both ends, thus constituting the pressure take-off points. A sensor placed inside the tube measures the pressure difference  
30   between its two ends. By way of example, the sensor can be constituted by a deformable membrane whose opposite faces come into contact with the well fluid as admitted via the two open ends of the tube.

35       In such conventional apparatuses, the distance between the pressure take-off points depends on the resolution of the sensors used. In early apparatuses using that measurement technique, the poor resolution of

the sensors available required a minimum distance of about 60 cm. This distance has generally been maintained ever since, even though sensors are now available of significantly higher performance.

5       Conventional apparatuses made in that manner provide results which are satisfactory when they are used in wells that are vertical or of small inclination. However, they are unusable in wells that are horizontal or that present a very high degree of inclination.

10

#### **Summary of the invention**

      An object of the invention is to provide a method whose original design enables the mean density of a fluid flowing in a hydrocarbon well in production to be  
15       determined when the well is greatly inclined or even horizontal.

      In accordance with the invention, this result is obtained by means of a method of determining the mean density  $\rho_m$  of a fluid flowing along a hydrocarbon well  
20       that is inclined or horizontal, the method being characterized in that it consists in measuring the pressure difference  $\Delta P$  between two regions situated close to the bottom and top generator lines of the well, in determining the inclination relative to the vertical of  
25       the straight line joining said regions, and in deducing the desired mean pressure  $\rho_m$  from the measured pressure difference and from the determined inclination.

      Because the pressure take-off points are situated close to the bottom and top generator lines of the well,  
30       the spacing between them in a vertical direction is substantially equal to the diameter of the well when the well is horizontal or greatly inclined. The resolution of presently-existing sensors is then high enough to be capable of determining the mean density of the fluid with  
35       the required accuracy.

      In order to make measurements easier in a non-horizontal well, said pressure difference  $\Delta P$  is measured

between two regions that are offset from each other parallel to a longitudinal axis of the well.

In the preferred embodiment of the invention, the pressure difference is measured between the two ends of a tube opening out into each of the above-mentioned regions.

In which case, it is advantageous to install the tube on an arm that is deployed substantially on a vertical midplane of the well so that the ends of the tube are placed close to the bottom and top generator lines of the well.

Preferably, the inclination relative to the vertical of the straight line joining together the above-mentioned regions is determined by measuring the inclination of the well relative to the vertical and the inclination of said straight line relative to the well.

The invention also provides apparatus for determining the mean density  $\rho_m$  of a fluid flowing along a hydrocarbon well that is inclined or horizontal, the apparatus being characterized in that it comprises pressure measurement means for measuring the pressure difference  $\Delta P$  between two regions situated in the vicinities of the bottom generator line and of the top generator line of the well, and inclination measuring means for determining the inclination of the straight line joining said regions, so as to be able to deduce the mean density of the fluid from the pressure difference as measured by the pressure measuring means and from the inclination as determined by the inclination measuring means.

When it is desired to perform redundant measurement, the apparatus has a body with two arms hinged thereto, in two different orientations. Each arm then carries a distinct tube associated with separate pressure-measuring means.

**Brief description of the drawing**

A preferred embodiment of the invention is described below by way of non-limiting example with reference to the accompanying drawing in which the sole figure is a diagrammatic longitudinal section through apparatus  
5 designed to measure the mean density of the fluid flowing in a well that is greatly inclined.

**Detailed description of a preferred embodiment of the  
10 invention**

The figure shows, highly diagrammatically, apparatus 10 placed in a hydrocarbon well 12 in production. More precisely, the portion of the well 12 containing the apparatus 10 is greatly inclined.

15 The apparatus 10 shown diagrammatically in the figure is designed to determine the mean density of the fluid flowing in the well 12. It may optionally be associated with other data acquisition apparatuses (not shown) and may have additional sensors which do not form  
20 part of the invention.

The apparatus 10 of the invention, and any other apparatuses that may optionally be associated therewith, is connected to a surface installation (not shown) by means of a cable or a flexible rod. The data acquired by  
25 the apparatus 10 is either recorded, or else transmitted in real time to the surface installation, by telemetry, via the cable or the rod.

The apparatus 10 of the invention comprises a cylindrical body 14 whose diameter is significantly  
30 smaller than the inside diameter of the well 12. The body 14 supports a hinged mechanism 16 suitable for being deployed in a plane that contains the longitudinal axis of said body.

In the embodiment shown in the figure, the mechanism  
35 16 comprises a tubular shoe 18 and two hinged arms 20 and 22 connecting the shoe 18 to the body 14. The structure of the mechanism 16 constituted in this way is such that

the body 14 and the tubular shoe 18 are pressed against diametrically opposite generator lines of the well 12 when the mechanism is deployed.

The mechanism 16 can also occupy a retracted state, in which the tubular shoe 18 is folded against the body 14 of the apparatus or is retracted into a housing provided for this purpose in the body 14.

To enable the mechanism 16 to pass from its retracted state to its deployed state, and vice versa, the arm 22 closer to the bottom of the well is hinged at both ends, respectively to the body 14 and to the tubular shoe 18. A first end of the arm 20 that is closer to the surface is hinged to the tubular body 18, while its opposite end is suitable for moving parallel to the longitudinal axis of the body 10 under drive from a motor (not shown) housed in the body 14.

In a variant embodiment (not shown), the arms 20 and 22 can be replaced by spring blades which serve to deploy the mechanism automatically when the apparatus is inserted into the well.

When the apparatus 10 is placed in a well that is inclined or horizontal, the body 14 automatically comes to rest on the lower portion of the well, i.e. against the bottom generator line thereof, as shown in the figure. When the mechanism 16 is deployed, it therefore automatically occupies the entire diameter of the well above the body 14 in a vertical plane that contains the longitudinal axis of the well.

In a variant, it is possible to fit the body 14 of the apparatus with a magnetic device. This device then co-operates with the metal casing 13 lining the inside of the well 12 so as to guarantee that the body 14 is properly oriented in the above-specified vertical plane.

In accordance with the invention, the apparatus 10 is fitted with means for measuring the pressure difference between two regions respectively situated close to the bottom generator line and close to the top

generator line of the well 12. In the embodiment shown, these means are duplicated so as to perform measurement in redundant manner.

5 More precisely, the apparatus 10 has two sensors 24 and 26 housed in the body 14. Each of the sensors 24 and 26 measures the pressure difference between the open ends of a corresponding tube 28 or 30.

10 The tube 28 extends along the arm 20 and passes through the body 14 and also through the tubular portion 18 so that its ends open out into regions B1 and H1 situated respectively in the immediate vicinities of the bottom generator line and of the top generator line of the well.

15 In comparable manner, the tube 30 runs along the arm 22 and passes through the body 14 and also through the tubular shoe 18 so as to open out at its ends in two regions B2 and H2 situated respectively in the immediate vicinities of the bottom generator line and of the top generator line of the well.

20 The sensors 24 and 26 placed in the tubes 28 and 30 respectively can be constituted by any sensor suitable for measuring the pressure difference to be found between the regions H1 and B1 and between the regions H2 and B2. Suitable sensors include, in particular, deformable  
25 diaphragm sensors or any sensor having sufficient resolution.

It should be observed that the regions H1 and B1 into which the tube 28 open out are offset parallel to the axis of the well. More precisely, the region H1  
30 situated in the immediate vicinity of the top generator line of the well is closer to the bottom of the well than is the region B1 situated in the vicinity of the bottom generator line of the well.

The regions H2 and B2 into which the tube 30 open  
35 out are also offset parallel to the axis of the well. Thus, the region B2 is closer to the bottom of the well than is the region H2.

The apparatus 10 of the invention also has three detectors 32, 34, and 36 housed within the body 14 of the apparatus.

5 The detector 32 measures the inclination  $\alpha$  of the well 12 relative to the vertical, i.e. the inclination of the axis of the body 14 relative to the vertical. It can be constituted by any detector suitable for performing this function.

10 Each of the detectors 34 and 36 serves to measure the respective inclinations  $\theta_1$  and  $\theta_2$  of the arms 20 and 22 relative to the axis of the well 12, i.e. relative to the longitudinal axis of the body 14. They can be constituted by any detector suitable for performing this function.

15 The various measurements performed by the sensors 24 and 26 and by the detectors 32, 34, and 36 are recorded and/or transmitted to the surface installation. They are used for calculating the mean density of the fluid flowing along the well. For each of the two pressure  
20 measurements performed by the sensors 24 and 26, the mean density  $\rho_m$  of the fluid is calculated using the following equation:

$$\Delta P = \rho_m \times g \times h$$

where:

- 25
- $\Delta P$  represents the pressure difference as measured by the sensor 24 or 26;
  - $g$  represents the acceleration due to gravity; and
  - $h$  represents the distance between the pressure take-off regions measured parallel to the vertical.

30 For the pressure measurement performed by the sensor 24, the distance  $h$  between the regions H1 and B1 is determined from the inclinations  $\alpha$  and  $\theta_1$  as measured by the detectors 32 and 34.

35 For the pressure measurement performed by the sensor 26, the distance  $h$  is calculated from the inclinations  $\alpha$  and  $\theta_2$  measured by the detectors 32 and 36.



The redundant nature of the measurements performed in the embodiment described makes it possible to be sure that at least one of the distances  $h$  over which the measurements are performed is at least substantially  
5 equal to the diameter of the well, regardless of the direction of its inclination. It is thus possible to determine the mean density of the fluid with good accuracy, even in a well that is greatly inclined or even horizontal.

10 Naturally, the invention is not limited to the embodiment described above. Thus, a simplified apparatus could have only one pressure measuring sensor, e.g. the sensor 26 as shown in the figure.

## CLAIMS

- 1/ A method of determining the mean density  $\rho_m$  of a fluid flowing along a hydrocarbon well (12) that is inclined or horizontal, the method being characterized in that it consists in measuring the pressure difference  $\Delta P$  between two regions (H1, B1; H2, B2) situated close to the bottom and top generator lines of the well, in determining the inclination relative to the vertical of the straight line joining said regions, and in deducing the desired mean pressure  $\rho_m$  from the measured pressure difference and from the determined inclination.
- 2/ A method according to claim 1, in which said pressure difference  $\Delta P$  is measured between two regions (H1, B1; H2, B2) that are offset from each other parallel to a longitudinal axis of the well (12).
- 3/ A method according to claim 1 or 2, in which said pressure difference  $\Delta P$  is measured between two ends of a tube (28; 30) opening out into each of said regions (H1, B1; H2, B2).
- 4/ A method according to claim 3, in which the tube (28; 30) is implanted on an arm (20, 22) which is deployed substantially in a vertical midplane of the well (12) in such a manner that said ends are placed in the vicinities respectively of the bottom generator line and of the top generator line of the well.
- 5/ A method according to any preceding claim, in which the inclination ( $\alpha$ ) of the well (12) relative to the vertical is measured and the inclination ( $\theta_1$ ,  $\theta_2$ ) of said straight line relative to the well is measured, from which the inclination relative to the vertical of the straight line is deduced.

6/ Apparatus for determining the mean density  $\rho_m$  of a fluid flowing along a hydrocarbon well (12) that is inclined or horizontal, the apparatus being characterized in that it comprises pressure measurement means (24, 26) for measuring the pressure difference  $\Delta P$  between two regions (H1, B1; H2, B2) situated in the vicinities of the bottom generator line and of the top generator line of the well, and inclination measuring means (32, 34, 36) for determining the inclination of the straight line joining said regions so as to be able to deduce the mean density ( $\rho_m$ ) of the fluid from the pressure difference as measured by the pressure measuring means (24, 26) and from the inclination as determined by the inclination measuring means (32, 34, 36).

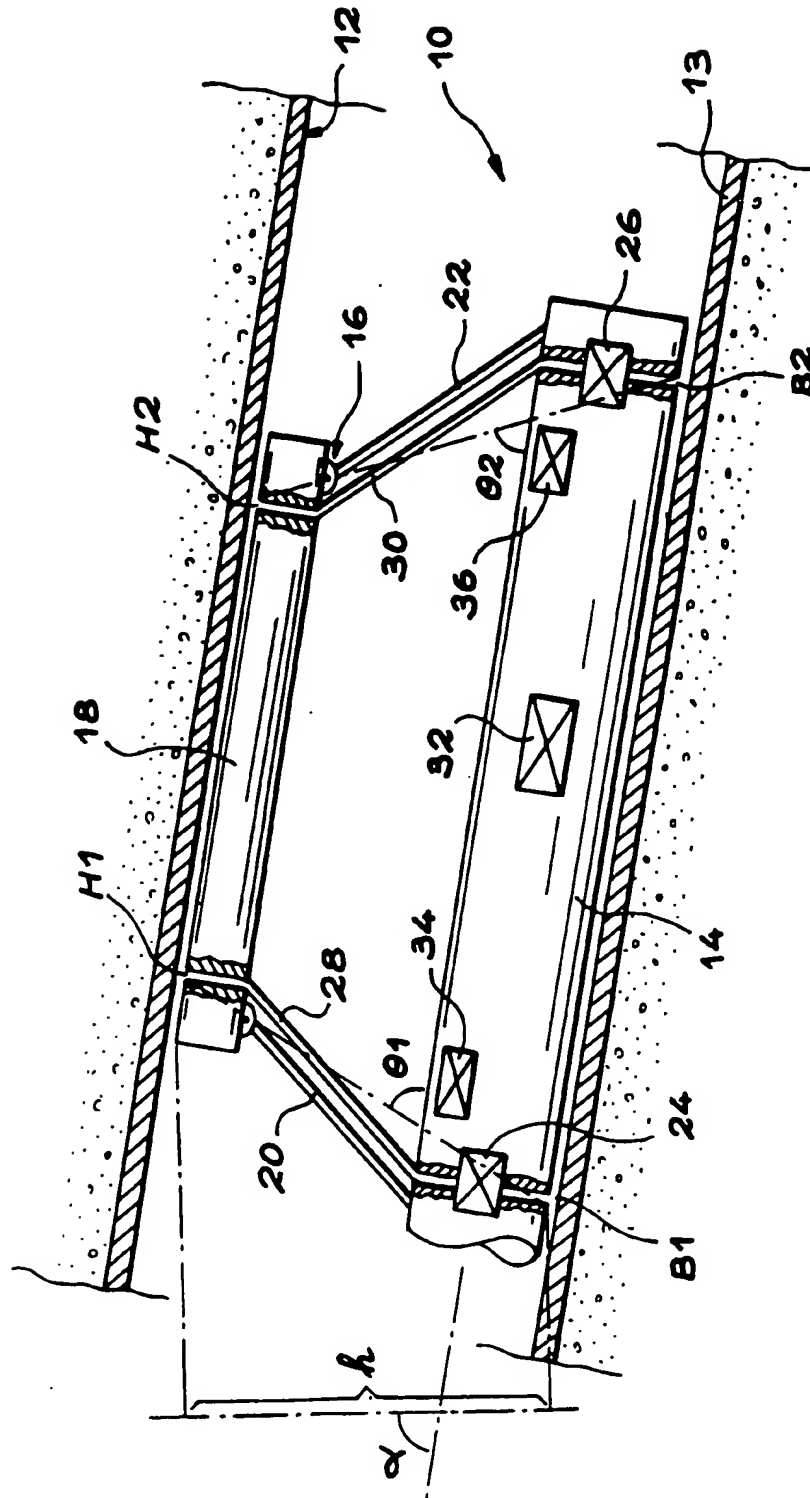
7/ Apparatus according to claim 6, in which the pressure measuring means (24, 26) measure said pressure difference  $\Delta P$  between two regions (H1, B1; H2, B2) that are offset from each other parallel to a longitudinal axis of the well.

8/ Apparatus according to claim 6 or 7, in which the pressure measuring means (24, 26) measure the pressure difference between two ends of a tube (28, 30) opening out into each of said regions (H1, B1; H2, B2).

9/ Apparatus according to claim 8, comprising a body (14) suitable for being received in the well substantially parallel to the axis of the well, and at least one arm (20, 22) hinged to the body (14) and suitable for being deployed in the well substantially on a vertical midplane thereof, said arm (20, 22) carrying the tube (28, 30) in such a manner that the ends of the tube are placed in the vicinities respectively of the bottom generator line and of the top generator line of the well.

10/ Apparatus according to claim 9, in which the inclination measuring means comprise a first detector (32) suitable for measuring the inclination ( $\alpha$ ) of the well relative to the vertical, and a second detector (34,  
5 36) suitable for measuring the inclination ( $\theta_1$ ,  $\theta_2$ ) relative to the body (14) of the straight line joining the ends of the tube (28, 30).

10 11/ Apparatus according to claim 9 or 10, in which two arms (20, 22) are hinged on the body (14) in different orientations, each arm carrying a distinct tube (28, 30) associated with separate pressure-measuring means (24, 26).



# INTERNATIONAL SEARCH REPORT

International Application No.

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**A. CLASSIFICATION OF SUBJECT MATTER**  
IPC 7 G01N9/26 E21B47/06

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 G01N E21B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 509 303 A (GEORGI DANIEL T) 23 April 1996 (1996-04-23) abstract; figures 1,2 column 1, line 34 -column 2, line 14 column 3, line 8 -column 5, line 30 ---	1-11
A	US 5 553 034 A (GEORGI DANIEL T ET AL) 3 September 1996 (1996-09-03) abstract; figure 2 column 1, line 65 -column 2, line 17 column 2, line 34 -column 2, line 38 column 3, line 29 -column 7, line 20 ---	1-11
A	US 5 509 312 A (DONZIER ERIC P ET AL) 23 April 1996 (1996-04-23) column 3, line 65 -column 4, line 50; figure 1 --- -/--	1,6

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

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# INTERNATIONAL SEARCH REPORT

International Application No.

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## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	<p>US 5 837 893 A (CHU WEI-CHUN)  17 November 1998 (1998-11-17)  abstract; figure 6  column 2, line 24 -column 2, line 44  column 5, line 27 -column 5, line 42  -----</p>	1,6

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Information on patent family members

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